

New tools for the study of oceanic eddies: Satellite derived inherent optical properties

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Abstract

Satellite study of oceanic eddy formation, propagation, interactions, and fate was first conducted by sea surface temperature derived at infrared wavelengths. For visible wavelength ocean color reflectances, it is shown that recent radiative transfer model inversions provide additional characteristics of eddies: their constituent absorption and backscattering inherent optical properties. The chromophoric dissolved organic matter absorption coefficient has the highest contrast and is therefore the most visually evident inherent optical property (while the phytoplankton absorption coefficient and backscattering coefficients are respectively less discernible). For use as an analytical tool, comparisons suggests that the chromophoric dissolved organic matter absorption coefficient has a $\sim 10\times$ higher contrast (i.e., $\sim 5\%$ vs. 50%) in the Middle Atlantic Bight making eddy events detectable over longer time periods than with SST imagery. Example imagery illustrates the application of chromophoric dissolved organic matter and phytoplankton absorption coefficient inherent optical properties to the visual injection of dissolved and particulate organic carbon into the deep ocean by a Gulf Stream ring.

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1. Introduction

To date, mesoscale studies of the oceanic eddies have largely used satellite sea surface temperature derived from thermal infrared wavelengths (Anonymous, 1981; Cornillon et al., 1994; Olsen, 1991). To a lesser degree other methods have been applied: (a) microwave satellite altimetry (Cheney et al., 1983; Hansen & Maul, 1991) and (b) visible wavelength empirically derived phytoplankton pigment concentrations (Garciamoliner & Yoder, 1994; Smith et al., 1987). The inherent optical property applications in this paper are discussed and compared only to the more abundant SST methodology.

To address the application of an inherent optical property (IOP) to eddy studies the work described herein uses, for example, Gulf Stream eddies that form rings. Long-lived eddies are frequently called rings and can be loosely defined as vortices that represent a wrapped-up piece of a major ocean current (Olsen, 1991). Simplistically, a ring forms when a linear ocean current becomes unstable and begins to meander. When the meander forms a “loop” that is almost closed upon itself, the current may again choose the shorter less restrictive linear path in such a way that the loop is pinched off and left to stand alone as a high velocity outer portion enclosing the water from which the meander originally departed. To date rings have been frequently described using a physical property of the water itself: temperature. Thus, for a current such as the Gulf Stream, poleward meanders give rise to warm core rings (WCRs) and equatorward meanders give rise to cold core rings (CCRs). In the northern hemisphere WCRs and

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Table 1

Eddy classification according to observables of the (a) ring water and (b) its optically active constituents

Water	Constituent IOPs		
Temp.	CDOM	Phytoplankton	Backscattering
WCR	DCCR	DPCR	DBCR
CCR	ECCR	EPCR	EBCR

WCR: warm core ring; CCR: cold core ring; DCCR: depressed CDOM core ring; ECCR: elevated CDOM core ring; DPCR: depressed phytoplankton core ring; EPCR: elevated phytoplankton core ring; DBCR: depressed backscattering core ring; EBCR: elevated backscattering core ring.

CCRs rotate clockwise (anticyclonic) and counterclockwise (cyclonic), respectively.

But the *constituents* carried within these poleward and equatorward water masses have observable signatures too (Hoge et al., 2001). These signatures are their absorption and backscattering IOPs. These IOPs serve as tracers of the ring and convey additional important information about its *physical* evolution, movement, and fate. More importantly, the IOPs convey important *geochemical* and *biological* information since, as will be shown, the chromophoric dissolved organic matter (CDOM) absorption coefficient, phytoplankton absorption coefficient, and backscattering coefficient IOPs of the rings can be concurrently mapped. From these latter IOPs it is hoped that the production, movement, and sequestration of carbon by rings can be obtained resulting in improved understanding of the carbon cycle and climate change. Estimates of carbon injected into the Middle Atlantic Bight will not likely change but the estimated amount transported to the deep ocean may change due to the robust CDOM absorption coefficient imagery available using the methods described herein.

It is the objective of this paper to (1) suggest additional tools for the study of oceanic eddies: IOPs, and (2) use IOP tools to demonstrate the visual injection of dissolved and particulate organic carbon into the deep ocean by a Gulf Stream ring.

Table 1 summarizes phenomena, abbreviations, nomenclature, and partitioning associated with eddy classification according to observables of the (a) ring water and (b) its optically active constituents. The description of the results will extensively utilize the abbreviations in Table 1.

4. Discussion and conclusions

In addition to elevated and depressed water temperature derived from infrared emission, six additional characteristics are now available for the study of oceanic eddies: the elevated and depressed inherent optical properties of the water's constituents: chromophoric dissolved organic matter absorption coefficient, phytoplankton absorption coefficient, and backscattering coefficient.

For eddy studies in the Middle Atlantic Bight during July and August, the CDOM absorption coefficient is seen to be the most evident of the three IOPs exhibiting a dynamic range of $\sim 6\times$. The highest visibility observed during this study is a new ECCR injected into the Sargasso Sea showing a ~ 0.02 to 0.15 m^{-1} range (see 19 July in Fig. 1). A similar contrast range is observed for a concurrent DCCR north of the Gulf Stream. The high visibility of ECCRs supports the finding that their diameter is in general larger than the corresponding EPCR.

The concurrent EPCRs show lower variability, $3\times$ corresponding to a range of ~ 0.01 – 0.03 m^{-1} (see 19 July of Fig. 2). The lower range is not unexpected since fairly low phytoplankton absorption is being injected into a region with existing phytoplankton absorption. It is therefore useful to use the high contrast ECCRs to assist in the location of EPCRs. In the case of the DPCR observed in July–August there is a similar $3\times$ variability range on the Middle Atlantic Bight shelf but visibility is complicated by the existing phytoplankton variability there.

For EBCRs and DBCRs their variability is low: only $\sim 25\%$ in August. Perhaps their qualitative visibility and utility (and the utility of EPCRs and DPCRs) could be improved by experimenting with various color scales (the color bar herein was by necessity held constant to illustrate the absolute levels of each IOP so that the relative level of each could be more easily be determined by the reader).

This initial effort at suggesting and defining IOP-rings for research investigations is brief, limited to a single oceanic region (the Middle Atlantic Bight), and restricted to the summer time period. Thus, much work remains to determine the usefulness of the suggested methodology here and in other oceanic provinces and seasons. This Middle Atlantic Bight region is rich in IOP eddy formations. Other western boundary currents such as the Kuroshio, Agulhas, and the weaker East Australian and Brazil Currents (Olsen, 1991) are also possible target research areas.

Comparison of concurrent Middle Atlantic Bight CDOM and SST imagery in August in the Middle Atlantic Bight showed that WCRs and CCRs show $\sim 5\%$ contrast relative to the surrounding water mass while the ECCRs and DCCRs show 45–65%. This $\sim 10\times$ higher contrast for CDOM imagery suggests that it is a valuable supplement to SST images for analysis of Gulf Stream eddies especially during the summer season when the temperature contrast is low. It is conjectured that eddies associated with other major oceanic current systems will show equally good visual contrast.